WDM-PON Overview

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> Summary

Introduction: why p-t-p network?

> Trends
- Bandwidth growth
  - 10 times every 5 years (Nielson's law, Optical Moore's law)
- Video centric services
  - High, bandwidth, high QoS, long connection time
  - Picture and video clip exchange
- Convergence over fiber based optical networks
  - Voice, data, video, and wireless (2G , 3G, LTE)
  - Residential and business

> Observations
- Long lifetime of outside plant
  - Fiber and passive devices guarantee > 25 years lifetime.
- TDM-PON
  - Ever changing technology: BPON → GPON → 10 G PON → 40 G PON
  - Limited scalability due to high speed transmission over high loss link

WDM PON Values

> Future proof solution
- Future proof Lifetime Outside Plant operation (>25years)
- Graceful Upgrade Path to Future High Bandwidth Applications

> WDM-PON scales dedicated BW to 1 G, 10 G and beyond

> Improved Customer Experience
- Secure symmetric p-t-p connection, No bandwidth sharing
- Bit rate and protocol transparencies
- Easy protection and fault localization

> Low Total Cost of Ownership
- Low OPEX cost effectively provided by colorless ONTs
- Low upgrade cost for future high bandwidth services
- One infrastructure for residential and business services
- Achieved inflection point for component industrialization start
- Significant improvements in WDM and DSP to improve reaches aiding in cost reduction

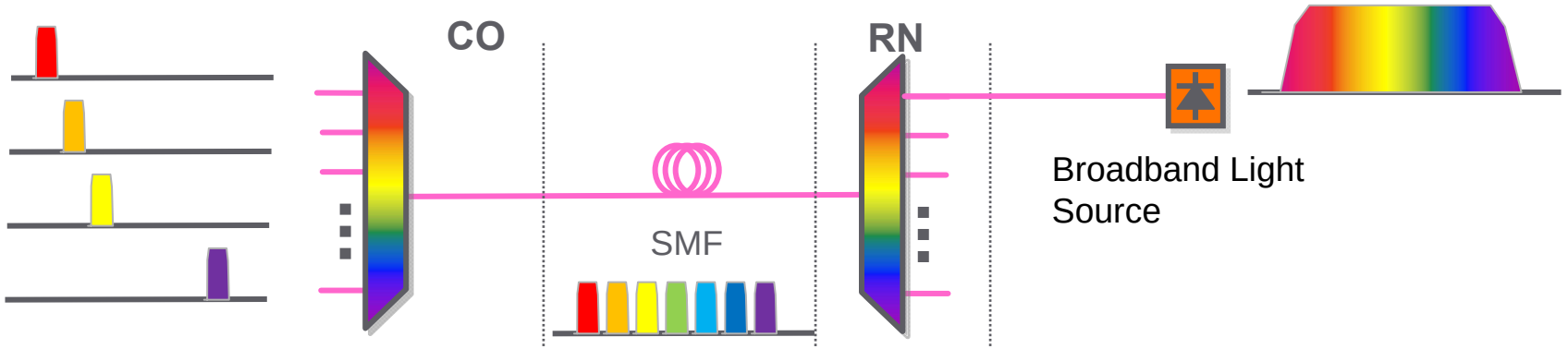
Colorless optical sources

> Colorless ONT (ONU) is essential for WDM-PON, since multiple users are connected to a PON.

> Methods for colorless operation

- Broadband light sources
  - A source that covers spectral range of transmission
  - Suffers slicing losses
- Injection seeding
  - Injection of seed light from a CO to ONT
  - ONT has an reflective modulator
  - Requires seed light
- Tunable lasers
  - A narrow band light tunable over spectral range of transmission
  - Needs prior information of wavelength

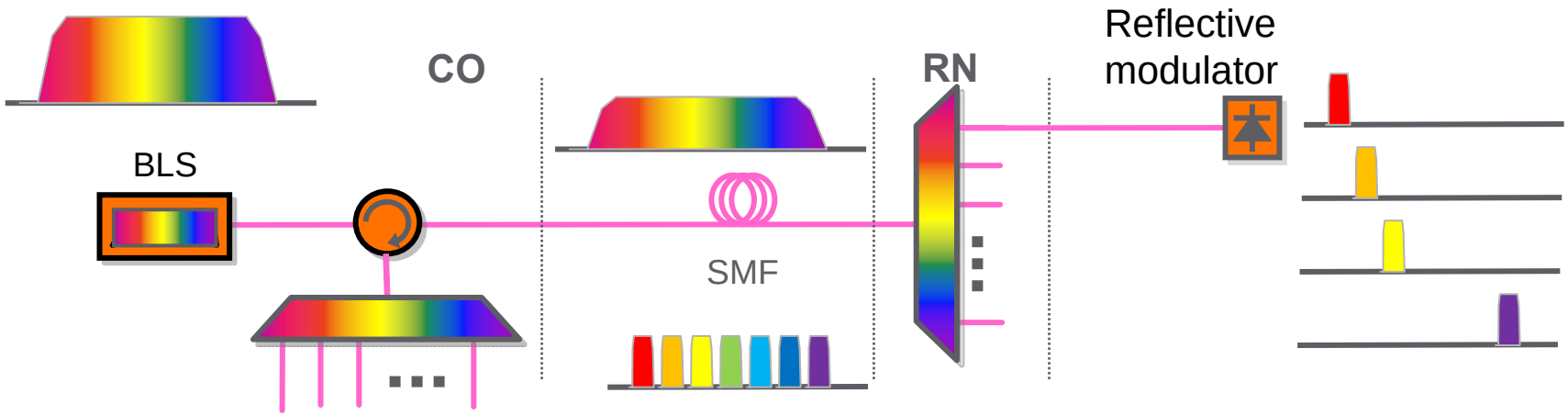
Broadband Light Sources



- A simple method

- Slicing loss > 1/N
- Limitation in modulation bandwidth for some sources
- Beat noises for an incoherent sources
  . Beat noise can be mitigated with a low noise multi-wavelength laser (e.g., QD laser).

Injection seeded reflective modulators

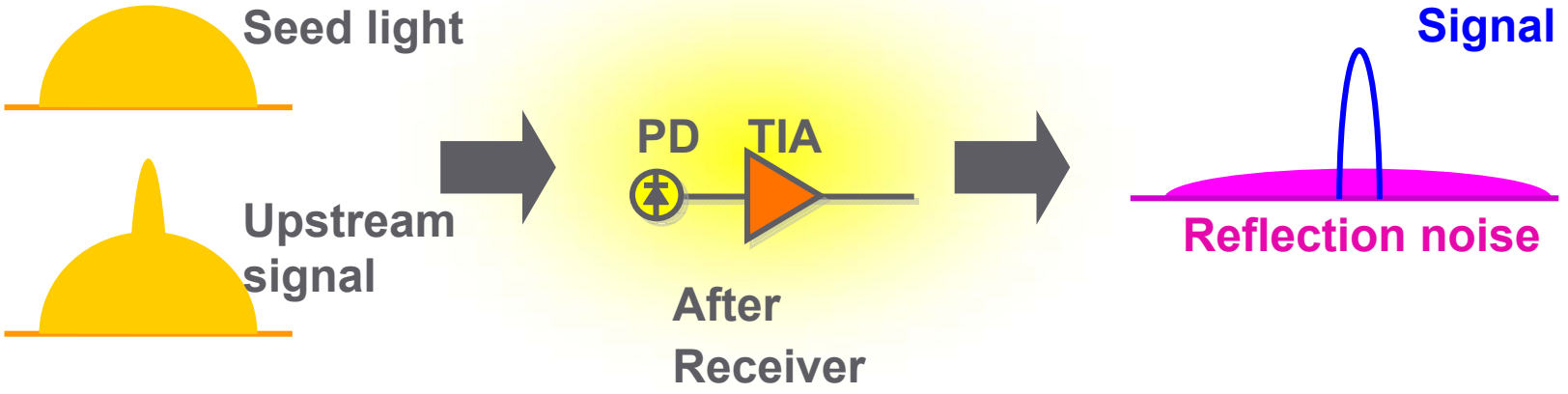


Seeding sources	Limiting factors	Reflective modulators
Incoherent light (ASE)	Source noise	F-P LD, RSOA, EA+SOA No restriction on spectral response
Coherent light (Bank of DFB LDs)	Reflection noises	RSOA, EA+SOA Restriction on spectral response
Downstream signal (incoherent or coherent)	Source noise/reflection noise Downstream penalty	Same as above

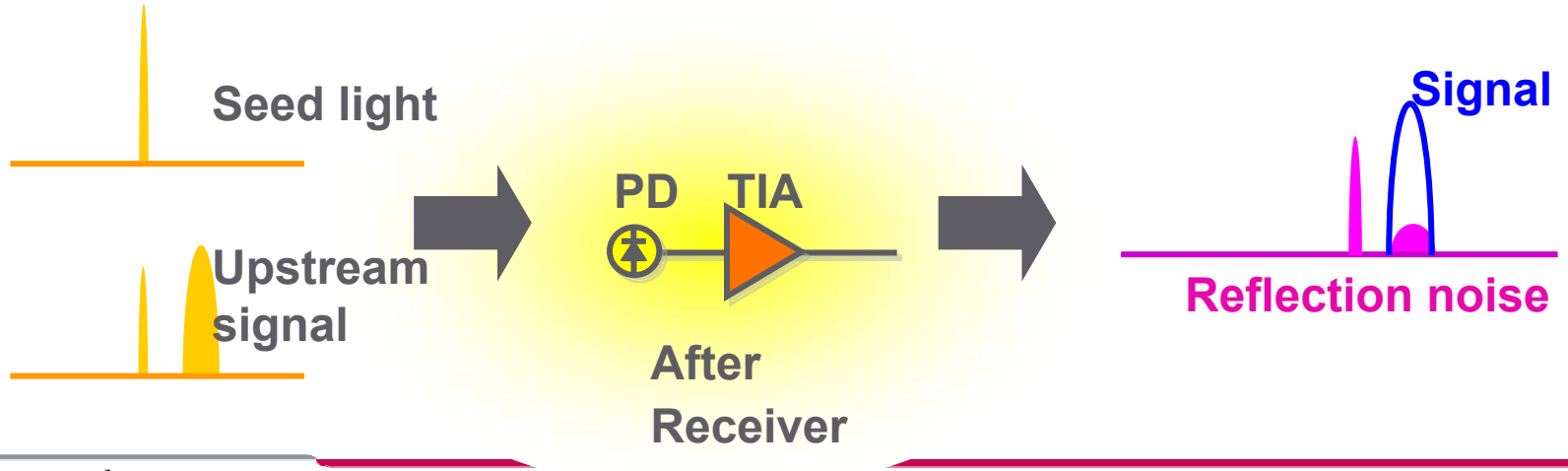
Reduction of Reflection Noises

> Broaden line-width of seed light

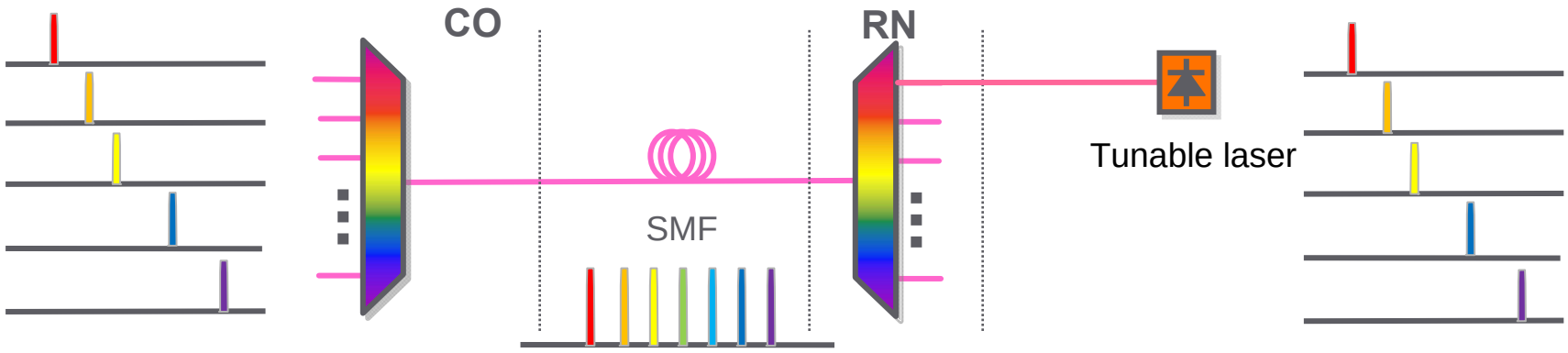
- Broadband seed light, phase modulation, …



> Shift of signal spectrum



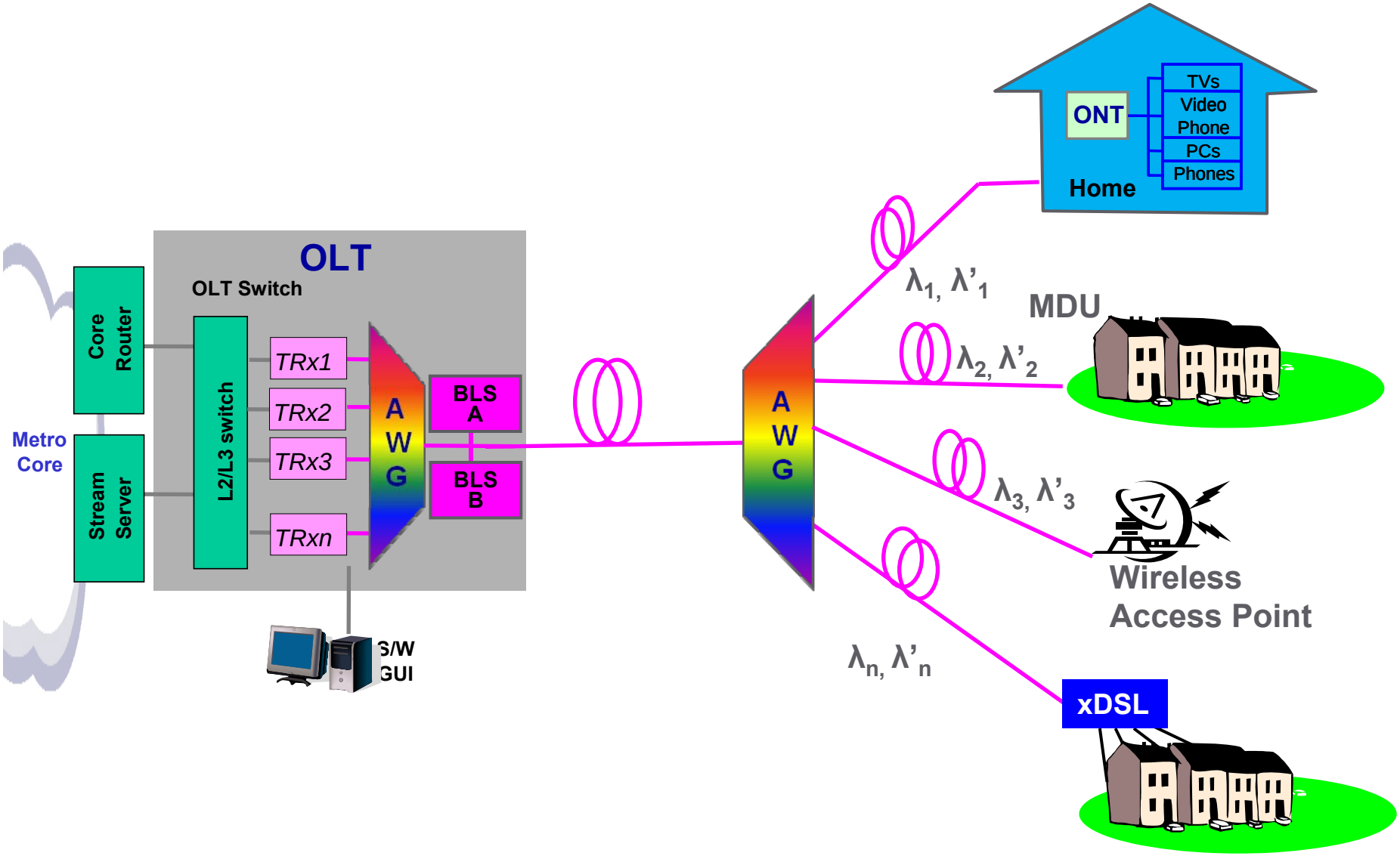
Tunable laser



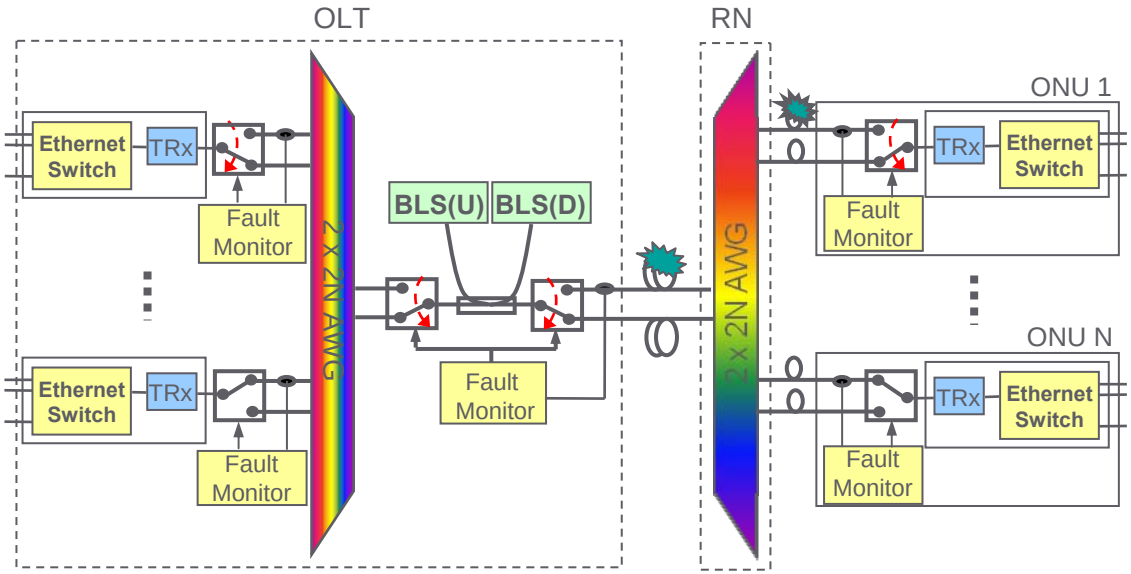
- No slicing loss
- Possibly high modulation bandwidth
- Low cost tunable lasers are the ultimate end goal.
- Coherent detection can improve link budget and channel counts.
  . Needs coherent tunable laser and DSP

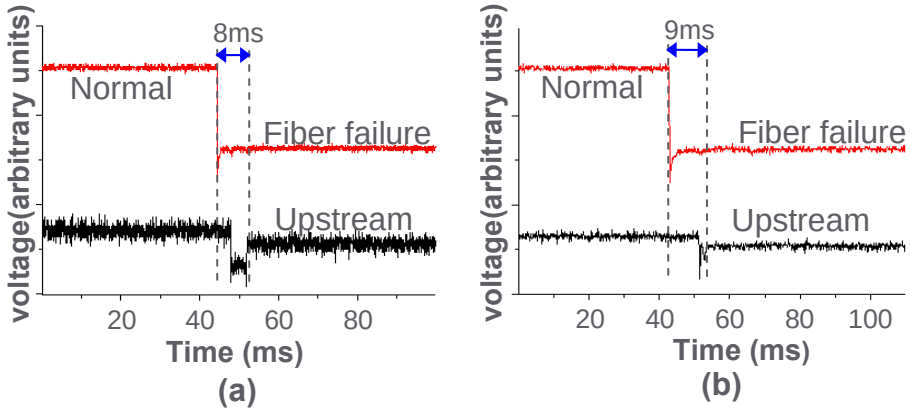
- Needs prior information for tuning wavelength
  . End to end control may be complex to mitigate.
- Cost is very high for access applications.

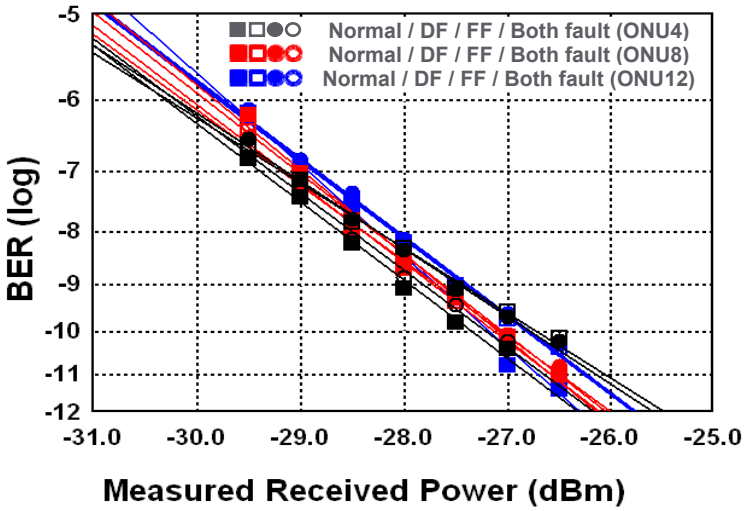
Architecture of WDM-PON



Protection of Fiber Faults

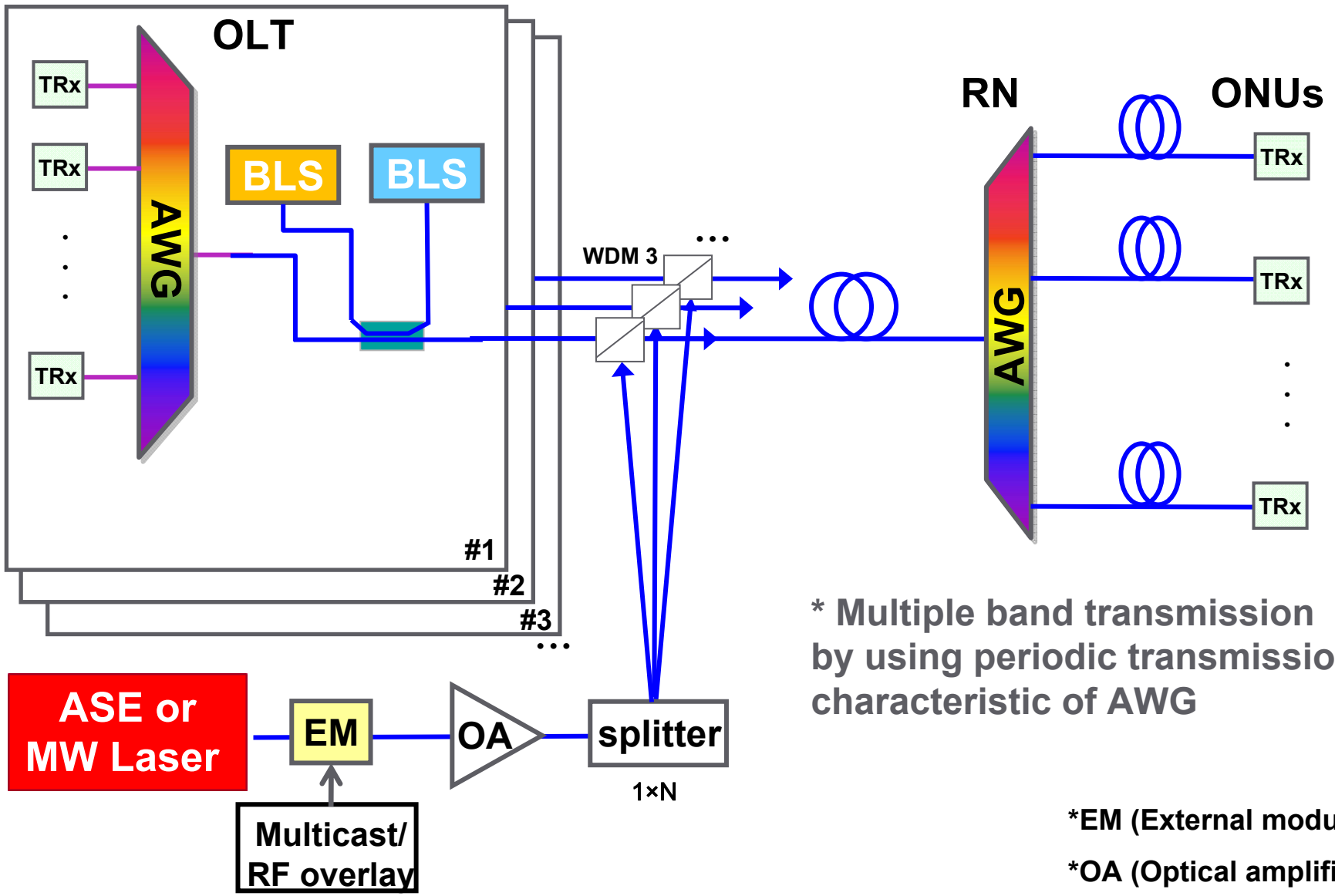






Switching Time

Broadcast/multicast in WDM-PON

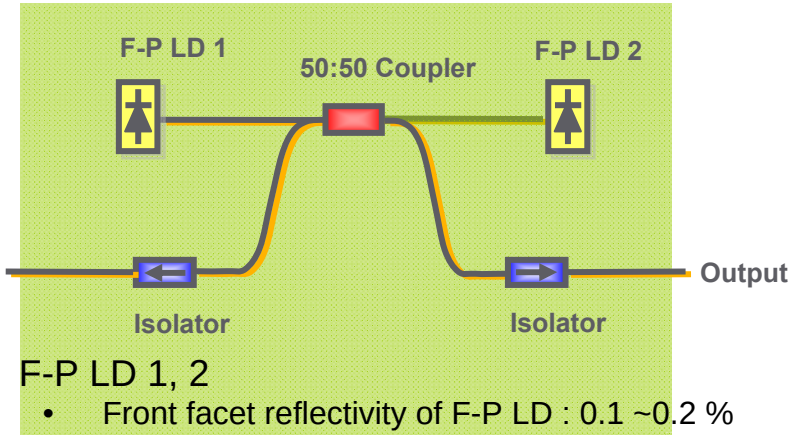


* Multiple band transmission by using periodic transmission characteristic of AWG

*EM (External modulator)

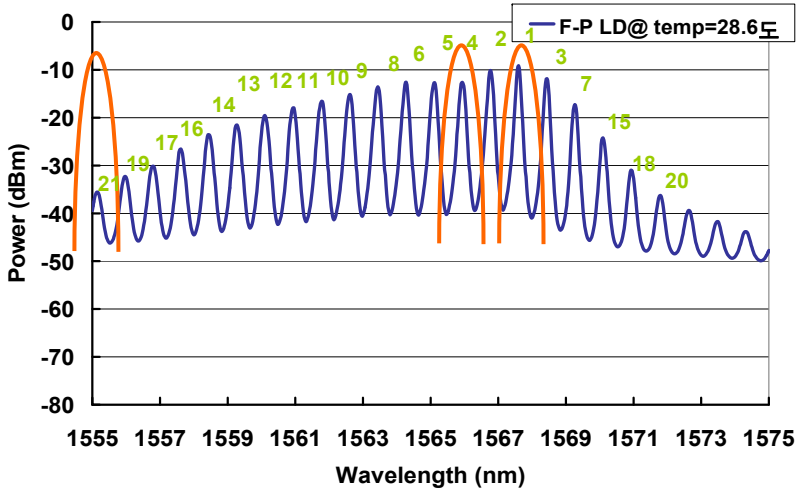
*OA (Optical amplifier)

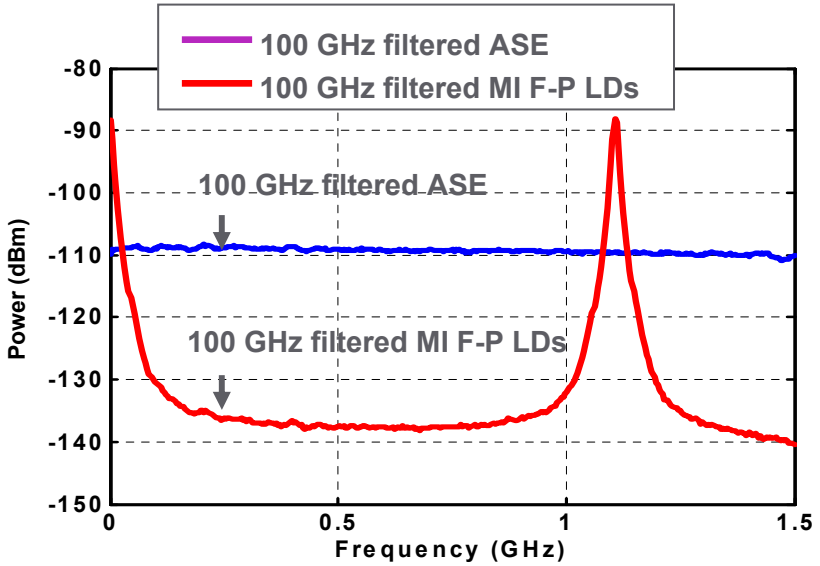
Broadcast signal transmission at 1.25 Gb/s channel

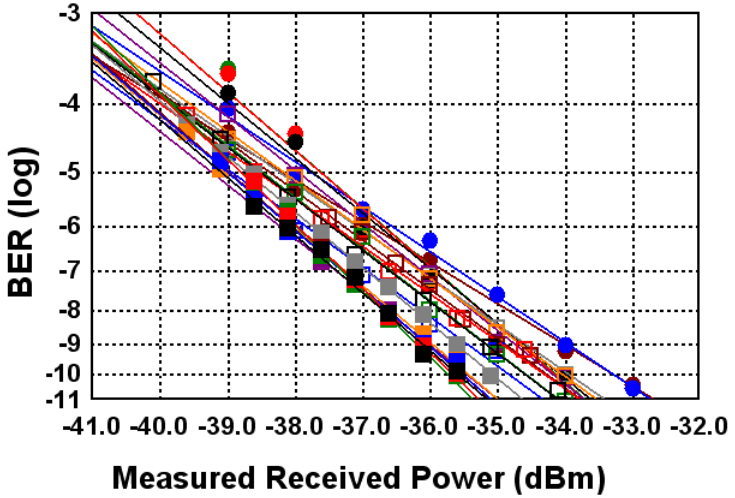


> F-P LD 1, 2
- Front facet reflectivity of F-P LD : 0.1 ~0.2 %
- Laser cavity length : 400 um

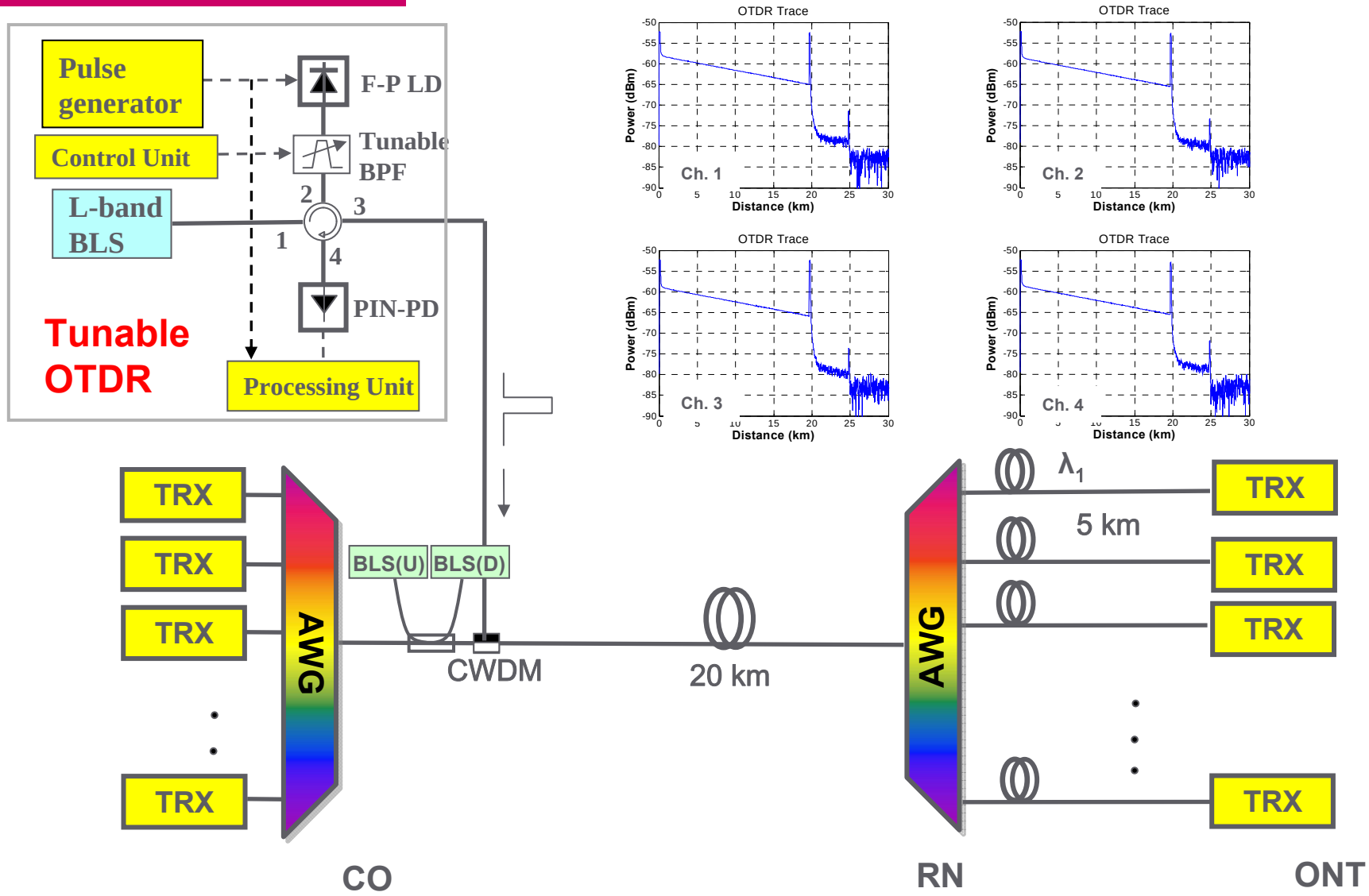
> Passive cavity length : 9 cm



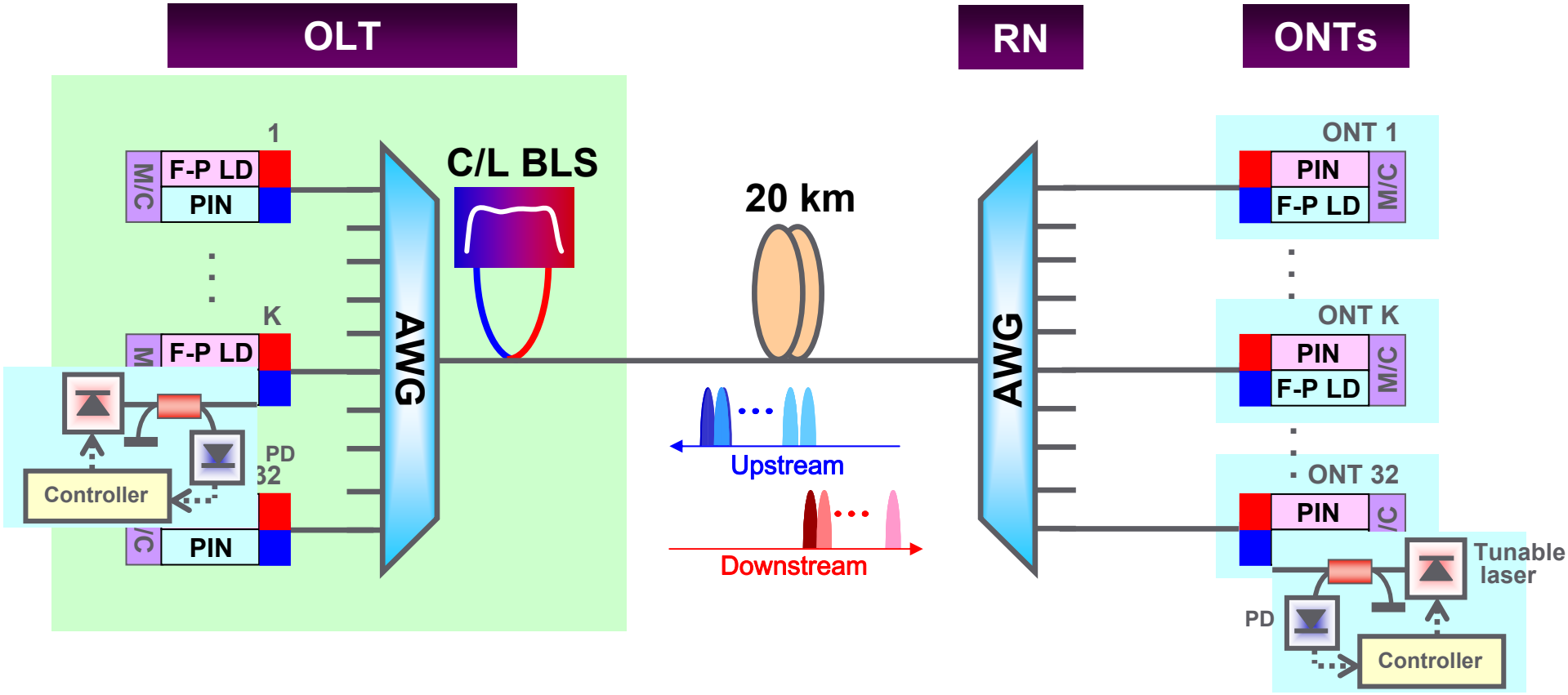




Fault localization with tunable OTDR

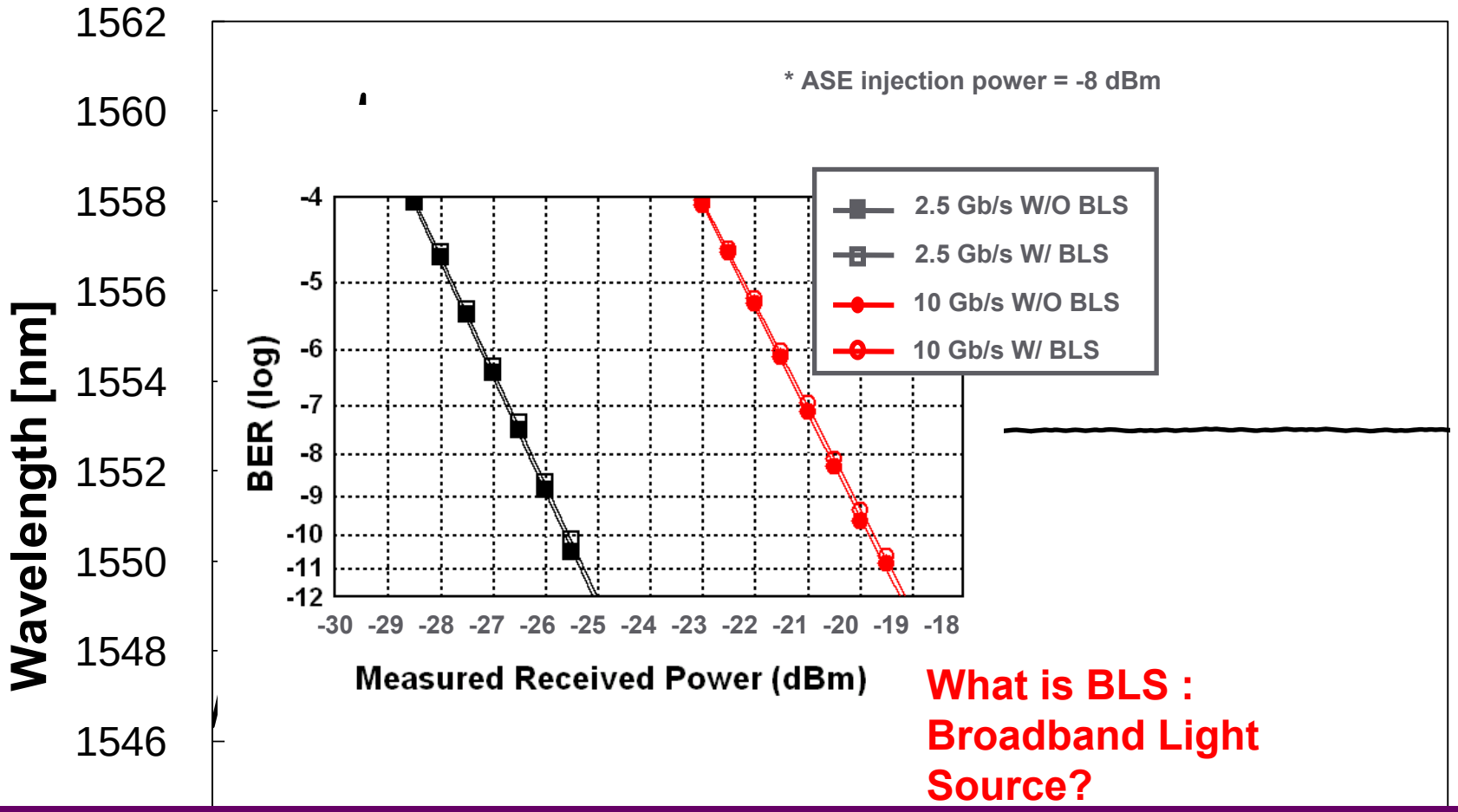


Upgrade to 10 Gb/s



Smooth migration is available to 10 Gb/s in WDM-PON based on the WL F-P LD by changing the transceivers both at OLT and ONT.

Self wavelength tracking



What is BLS : Broadband Light Source?

BLS induced penalty is negligible.

LONG Reach WDM-PON

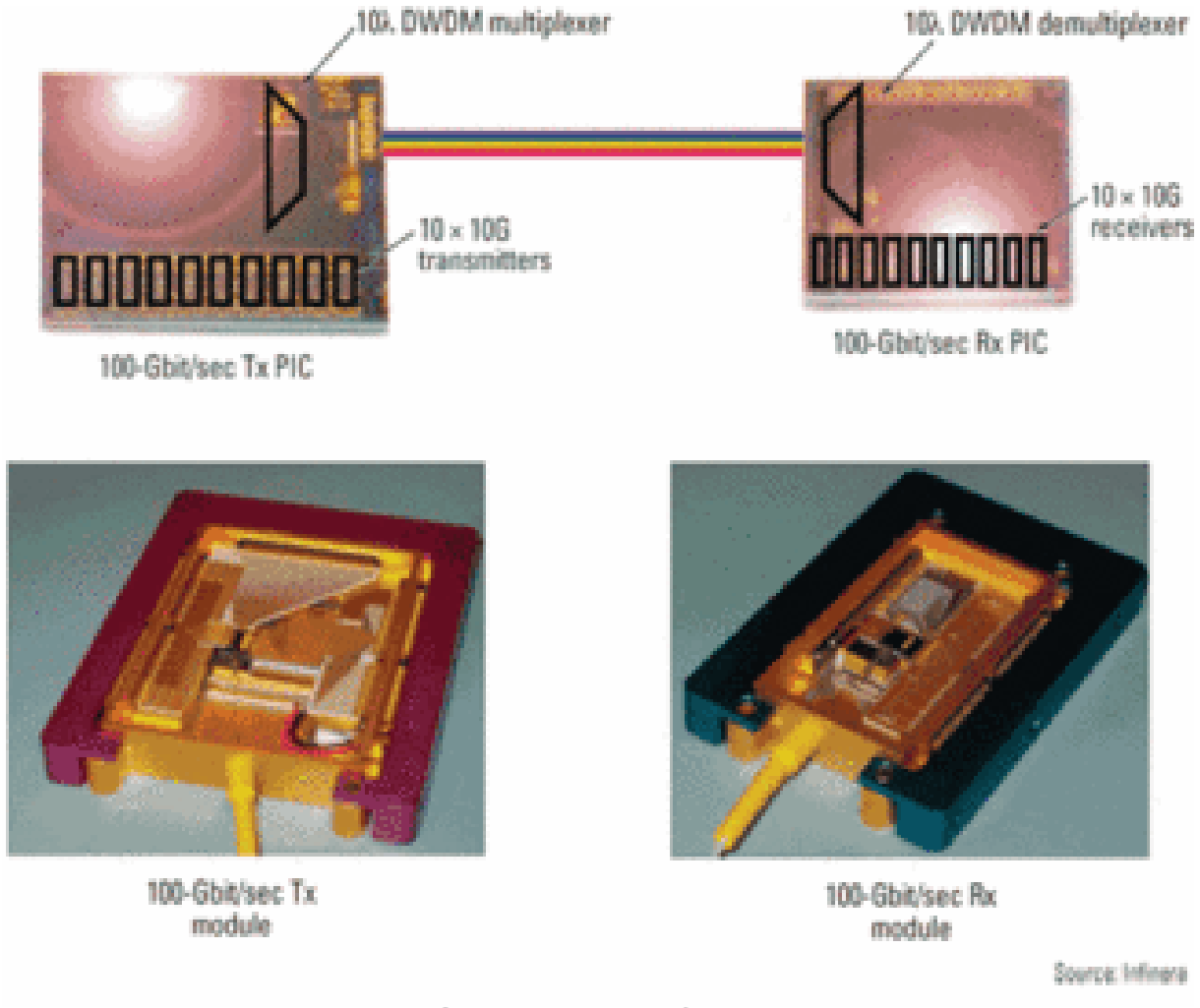
> Passive long reach WDM-PON
  - Fiber Raman amplifier
  - Remote pumped EDFA
  - Reduction of reflection noise is a major issue for injection seeding method.

> Skipping CO with simple active elements
  - Seeding sources
  - Optical amplifiers
  - Hybrid WDM/TDM-PON
    - Increases split ratio up to ~1,000
      - Solves fiber bottleneck in metro section
    - Limited guaranteed bandwidth per user
      - Requires high bit rate transmission TDM-PON

Devices for WDM-PON

- Broadband light sources
  - Amplified spontaneous emission
    - Semiconductor based (direct modulation): LED, SLD, …
    - Doped fiber based (external modulation): EDFA, PDFA, ….
  - Multi-wavelength laser (e.g. QD laser)
    - Low noise
    - Direct modulation capability is desired.
- Reflective modulators
  - F-P LD or RSOA
  - Electro-absorption modulator integrated with SOA
- Tunable laser
  - Multi-section DFB/DBR laser, VCSEL
  - PLC type tunable laser
- Athermal AWG
  - Periodic transmission characteristics

High density OLT



Source : Infinera

WDM-PON – Global Status

> WDM-PONs based on injection seeded BLS were commercialized.

> Global deployment underway

- Successful commercial deployment in Korea and Europe
- Several Lab, field trials & FOA in US, Canada, Japan, Taiwan

> 125 Mb/s per channel systems:

- 32 channels, 40 km reach capable today
    - Residential and Business users
- Qualified and deployed in KT network since 2005: 200K users

> 1.25 Gb/s per channel:

- 16 channels, 20 km reach available today.
- 32 channels system (40 Gb/s) in near future
- Fully colorless operation; High immunity on optical back reflection

WDM-PON vs. TDM-PON

Multiple access (upstream)	WDMA	TDMA
Downstream	WDM	TDM
Guaranteed BW	Line rate	Line rate / N (BW sharing)
Burst mode	No	OLT and ONT
Statistical gain	No	Yes
Splitting loss [dB]	3 – 5 dB (WDM filter loss)	16 - 17 dB (1 x 32 splitter)
SNR penalty	No	$N^4 \sim N^5$
Bit rate transparency	Unlimited	~ 10 Gb/s
Protocol transparency	Yes	No
Open architecture and unbundling support	Easy	Difficult
Fault localization (OTDR)	Easy	Difficult
Key technologies	- Color free optical source	- High speed transmission - Burst mode receiver

Summary

> Bandwidth Demands are growing (witness this activity)

- Engage now to address current and emerging network requirements

> WDM-PON is one of the lead candidates for NGA2

> WDM-PON technology ready for deployment now

- Provides future proof OSP and low TCO
- Components are available now to build systems
- IEEE Standard Ethernet protocol and industry accepted OAM
- Complementary to NGA1 and new green field applications